

## GAS FLOW MEASUREMENT DEVICE

### Field of the Invention

The present invention relates to a device for measuring the flow rate of a gas through a conduit, and in particular for measuring the flow rate of breathable gas flow associated with a non-invasive positive pressure ventilation (NIPPV) apparatus, continuous positive airway pressure (CPAP) apparatus, ventilatory assist device, or the like.

### Definition of Terms

The term 'conduit', used herein, is to be understood in a non-limiting sense. Particularly, it is not limited only to a flexible air hose that interconnects a flow generator with a patient mask for CPAP or assisted ventilation equipment.

In this specification, the phrases 'encode', 'encoder' or 'encoded' are to be understood as meaning any apparatus or operation that effects the fraction of transmitted light which is received by a detector.

### Background of the Invention

NIPPV apparatus function to supply a patient with clean breathable gas (usually air, with or without supplemental oxygen) at a therapeutic pressure or pressures, at appropriate times during the subject's breathing cycle. Such apparatus includes a blower to produce a flow of pressurised breathable gas, a gas supply conduit to receive said gas and an interface, typically a nasal mask, in turn to deliver the gas to the patient's airways. Further, there is a controller having control over operation of the blower, and a flow measuring device. Typical pressures delivered are in the range of 2 to 30 cm H<sub>2</sub>O. Typical flow rates are in the range of -150 to 300 L/min. For certain applications in the field of NIPPV and CPAP it is necessary to detect flow signals with a frequency in the range 0 to 30Hz.

Measurement of the volumetric flowrate of gas ("flow") in CPAP or ventilatory assistance devices is required for calculating the subject's ventilation, and to detect changes between the inspiratory and expiratory phases of breathing. It is very important that flow be determined accurately.

Typically, fixed or variable orifice meters are used to determine flow. In these meters, a pressure transducer measures the pressure differential across a fixed or variable orifice. Problems with orifice meters include high pressure drop, poor gain and poor linearity at low flows.

Another known device for measuring the flow rate of a gas is the moving vane flow meter. In these meters, movement of the vane varies or produces changes in an inductive or capacitive electrical signal. Problems with the moving vane transducers include poor dynamic response and limited bandwidth. A further disadvantage of the moving vane transducer is that variations in ambient air temperature and air density can result in measurement errors. This is because the vane transducer inherently measures air mass, rather than air volume.

More sophisticated devices such as thermal flow meters (which measure the molecular flow of gas) and turbine type devices are generally too large and expensive for applications in the field of CPAP and NIPPV.

It is an object of the invention to overcome or at least ameliorate one or more of the disadvantages of the prior art.

### Summary of the Invention

The invention discloses a measuring device for determining gas flow through a conduit, said device comprising:

- a vane arrangement extending into the conduit to be displaceable under the influence of gas flow in the conduit;

- a light source arranged to provide a uniform intensity of light over a range of displacement of the vane arrangement;

- an optical encoder interposed between the light source and the vane arrangement effective over the range of displacement to encode the light source as a function of displacement of the vane arrangement under the influence of gas flow; and

- a light detector arranged to optically communicate with the encoded light source and provide an output signal based thereupon related to gas flow.

In one form, the vane arrangement forms at least one light guide, and the encoder is interposed between one or more free ends of the light guide and the light source so that

the encoded light is optically communicated to one or more light guides. In another form, the vane arrangement has two light guides, and the encoder has two rows of regularly spaced discrete light sources aligned with a free end of the respective light guide. In a further form, the vane arrangement carries a first polarizing element, and the first polarizing element and a second, fixed polarizing element form the optical encoder. The light source, first and second polarizing elements and the light detector are in optical alignment, with the planes of polarization of the respective first and second polarizing elements interacting as a function of displacement of the vane element to result in a range of optical transmittivities.

A measuring device as described above can be included in CPAP or ventilatory assistance devices. Such apparatus includes a blower to produce pressurized breathable gas, a gas supply conduit to receive said gas and a device, typically a mask, in turn to deliver the gas to the patient's airways. Further, there is a controller having control over operation of the blower, and the flow measuring device provides its output gas flow signal to the controller as a control variable therefor.

The invention further discloses a method for detecting gas flow through a conduit, comprising the steps of:

- encoding the light source as a function of a displacement of a vane arrangement located within the conduit under the influence of gas flow; and
- detecting the encoded light and producing an output signal representative thereof related to gas flow.

**Brief Description of the Drawings**

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of a longitudinal cross-section of a conduit, fitted with first form of flow sensor;

Fig. 2 is a flattened plan view of a mask used in the flow sensor of Fig. 1;

Fig. 3 is a longitudinal cross-section of a conduit, fitted with a second form of flow sensor;

Fig. 4 is a longitudinal cross-section of a conduit, fitted with a third form of flow sensor;

Fig. 5 is a transverse cross-section of the conduit and flow sensor of Fig. 1;

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Fig. 6 is a perspective view of a longitudinal cross-section of a conduit, fitted with a fourth form of flow sensor;

Fig. 7 is a timing diagram used in the embodiment of Fig. 6;

Figs. 8a and 8b are schematic diagrams of a fifth form of a flow sensor, having a digital encoder and circular section flexible light guides;

Figs. 9a-9d are schematic diagrams of a sixth form of flow sensor, using polarizing films;

Fig. 10 is a graph showing the relation between sensor output voltage versus flow;

Fig. 11 is a graph comparing the experimental output/flow characteristics for a set of measurements and theoretical calculations; and

Fig. 12 is a schematic diagram of CPAP or assisted ventilation apparatus incorporating a flow sensor.

#### Detailed Description of the Preferred Embodiments and Best Mode

Referring to Fig. 1, there is shown a flow sensor 10 arranged inside a conduit 12 associated with a CPAP apparatus, ventilatory assist device, or the like. The conduit 12 provides a path for breathable gas to flow in either direction, denoted by reference numeral 11. The flow sensor can be positioned in the air conduit, near the patient mask or generally at some position downstream of the blower sourcing the breathable gas.

The flow sensor 10 includes a "light-pipe" vane 14, an arcuate portion 13, and a light detector 20. The vane 14 is formed from a very light polymer material such as acrylic, that is optically transparent. The shape of the vane 14 can be other than shown in Fig. 1, as will be later discussed in relation to Fig. 5.

The vane 14 extends from an attachment end 19 formed in a wall portion of the conduit 12 such that a free end 18 of the vane 14 is able to swing substantially throughout a range extending over the arcuate portion 13 in response to gas flow through the conduit 12. A constant radial distance is maintained between an upper plane 9 of the arcuate portion 13 and a polished end surface 8 of the free end 18 during a full range of normal movement of the vane 14.

When light from a uniform light source 16 reaches the arcuate portion 13, subject to the influence of an encoder, in the form of a mask 24 located on the arcuate portion 13,

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the polished end surface 8 of the free end 18 receives and transmits light in a lengthwise direction 15 through the length of the vane 14.

The relationship of gas flow to radial displacement of the vane 14 though the arcuate portion 13 is typically non-linear. This non-linearity can be compensated, if necessary, by adopting a mask shape 24' having an aperture 26, as shown in Fig. 2. Alternatively, this non-linear characteristic can be compensated in post-detection processing.

The attachment end 19 of the vane 14 is in optical contact with a detection face 22 of the light detector 20. The light detector 20 provides an electrical output signal at the pins 23 according to an intensity of light received on the detection face 22 which has travelled in direction 15 discussed above. A suitable detector is the Honeywell™ phototransmitter #SD3443, used in its linear range. The intensity of light received on the detection face 22 corresponds to the position of the polished end surface 8 of the vane 14 in relation to the arcuate portion 13, by virtue of the variation of light source intensity transmitted through the mask 24, 24'.

The flow sensor 10 can be used to determine gas flow direction by virtue of the smallest aperture/minimum detected voltage output at the pins 23, occurring at a maximum flow position of the vane 14 in a first direction. A largest aperture/maximum detected voltage output at pins 23 occurs at the maximum flow position of the vane 14 in a second, opposite direction. Zero gas flow therefore occurs when a voltage output at pin 23 equals a mid-voltage value between the maximum and minimum values.

The light source 16 is desirably of uniform intensity across the full range of the aperture 26 of the mask 24 which communicates with a polished end surface of the free end 18. This uniformity of the light source 16 can be achieved in various ways, as will now be discussed.

Referring to Fig. 3, which is a cross-sectional view of the flow sensor 10, the light source 16 can be an electro-luminescent film (e.g., Selkosh™ EL film) formed into the required curved shape and be directly laminated on a back face of the mask 24. An alternative can be an LED back-lit panel.

A further alternative arrangement for achieving a uniform light source is shown in Fig. 4, where a light diffuser 30 is placed between a lamp 31 (or lamps) provided externally to the arcuate portion 13.

The mask 24, serving as an analogue intensity encoder, can be manufactured in various ways, including a photographically produced opaque outline onto translucent glass or polymer, or laser cut/chemically etched thin metal film. It can also be integral of the arcuate portion 13, for example, as an injection molded part.

Referring to Fig. 5, another form of vane 25 is shown in transverse cross-section with respect to a conduit 26. A housing 32 extends from the conduit, in which the light source 16 is located. The free end 27 of the vane 25 is generally wider than an attachment end 28, so as to provide a maximum bending angle of the vane 25 throughout the arcuate portion 13, for a given surface area of the vane 25 presented to gas flow in the conduit 26. This minimisation of the surface area of the upper portion of the vane 25 minimises gas flow restriction, inertia and pressure losses that are usually associated with prior art vane sensors.

The light transmission path 29 of the vane 25 is an optical fibre of flattened rectangular cross-section. Typically, there will be minimal light entering the vane 25 through the side walls, due to the small angles of incidence to those surfaces which (obeying Snell's law) results mostly in external reflection from the surfaces. However, if otherwise necessary, the entire vane 25, except for the polished end, can be coated with opaque material.

A yet further form of flow sensor will now be described with reference to Figs. 6 and 7. Here, the varying aperture (analog) encoding mask 24 of Fig. 5 is replaced with a 'digital' encoder in the form of having two rows (channels) of slots 44, 45, each row being parallel to the gas flow direction 11 as shown. The vane 41 is split into two separate light pipes 46, 47, each of which corresponds to one of the two provided rows of slots 44, 45 of the mask 40. A pair of light detectors (not shown) are also provided, each of which correspond to a single row of slots 44, 45 and its associated light guide 46, 47. The encoder-type mask 40 can be manufactured using the same processes as that described earlier for the analog mask.

When the vane 41 is displaced in response to gas flow through the conduit, the amplitude of the light received for each of the two channels is detected as pulses, which can be processed as digital signals. An example of a suitable detector is the Honeywell™ Optoschmitt detector #SD5620-1. Similar to the arrangement shown in Fig. 1, a light detector is placed at the receiving attachment end of each of the two channels.

By spacing the two channels 90 degrees (electrical) apart, as shown in Fig. 7, (in the direction of vane movement) the directions of motion can be determined by the unique combination of paired outputs of the digital state of each of the detectors in channels A & B. For example, movement of the light guides in one direction may result in an output of (1,1) (1,0), (0,0), (0,1) (1,1). Movement in the reverse direction may result in the following output: (1,1), (0,1), (0,0), (1,0) and (1,1). These two patterns are distinct and hence flow direction can be determined.

The quantity 360 electrical degrees is the distance between corresponding slots, equivalent to the distance between successive rising edges of the resultant electrical pulses. Therefore, 90 electrical degrees is equivalent to 1/4 wavelength.

The value of flow is determined by the absolute number of output pulses counted, relative to the zero count (i.e. flow generator/blower off). Changes in flow are determined by incremental changes in encoder output.

Further, the vane movement versus flow relationship can be linearized by either spacing the slots in a non-linear pre-determined pattern, or linearized in post-detection processing. The "home" or indexed position of the encoder is defined during machine start-up as being zero pulses at zero flow.

A principal advantage of the embodiment of Figs. 6 and 7 is that a digital TTL/LSTTL/CMOS compatible output can be provided for direct interfacing to digital circuitry. This usually results in a more stable output and a reduction in parts costs (e.g., an analogue-to-digital conversion is not required).

The function of light guides may also be achieved by the use of optical fibers of circular cross-section (typically in the range 1.0 to 1.5 mm diameter), rather than of





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transmitted to a detector on the other side of the films is increased or decreased depending on the initial polarizing orientation, and the angle of rotation.

As shown in Figs. 9a and 9b, a flow sensor has one fixed polarizing film 90, polarizing its surface being parallel to flow in the conduit 12, and a second parallel film 92 in the shape of an arc fixed to the shaft portion of a lightweight vane 96. The vane has a small sail 98 at its free end in order to assist in achieving an appropriate deflection.

The two films are arranged so that the light from an LED 100 (or similar source), mounted on one side of the conduit 12, is directed along a line perpendicular (i.e. in alignment with) to the two polarizing films 90, 92 to be detected by a detector 102 on the other side of the conduit 12. The two films 90, 92 act as an optical encoder, in this case by the interaction of the relative orientation of their planes of polarization. The alignment shown in Figs. 9a and 9b corresponds to zero flow, and is at the mid-point of the moving polarizing film 92.

At zero flow, the polarizing planes of the two films 90, 92 must be aligned somewhere between 0 and 90° orientation relative to each other. This is necessary in bi-directional flow applications whereby flow direction is determined according to whether the detected light intensity increases for flow in one direction, or decreases for flow in the other direction.

As shown in Figs. 9c and 9d, the maximum and minimum detected light intensities occur at 90°, i.e. when the polarizing planes of the two films are either perpendicular or parallel.

The sensor output voltage versus flow characteristic, for the sensor of Figs. 9a-9d, is shown in Fig. 10, where the flow variable was determined using a hot-wire flow meter. The triangle, square and diamond symbols shown represent each of three tests.

Fig. 11 shows the experimentally determined characteristic of Fig. 10 mapped against a theoretical prediction, showing good correlation. The theoretical curve has been determined from the following equations:

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$$Q = (A_1 - A_2 \Omega) \sqrt{\frac{K_1 \cos^{-1} \Omega}{K_1 \cos^2 \Omega}}$$

where:

$A_1$ : Cross-sectional area of the housing inlet

$A_2$ : Cross-sectional area of pressure drag (the vane)

$K_1$ : Spring constant

$$\Omega = \sqrt{\frac{I}{I_{\max}}}$$

$I$ : Light intensity

$K_1$ : A system parameter

A general procedure which calibrates the flow transducer in all its forms, whenever the gas blower associated with the conduit, to which the flow transducer is measuring, is started will now be described. This calibration procedure includes the operation of a blower at a specific condition (e.g., pump/motor speed or applied motor voltage), which normally corresponds to a known flow rate (say 150 l/min) at original manufacture conditions. During subsequent start-ups of the blower at any other environmental condition, the indicated flow rate would be compared to the original calibrated flow value, thereby permitting a correction to be made, if necessary.

The corrections that can be made to the measured gas flow include: (i) a constant off-set value, (ii) a percentage of the indicated value, or (iii) a non-linear correction. The correction may be set until the next time the gas blower is started.

The environmental conditions that would normally be expected to affect air density, and consequently the accuracy of the flow meter, includes changes in relative humidity, altitude and ambient temperature. Because of the calibration adjustment, the sensor voltage output/logic value at zero flow is unchanged by variations in the environmental factors described.

Fig. 12 shows a representative schematic diagram for CPAP or assisted ventilation apparatus. A flow generator 100 provides pressurized gas to a patient mask 102 via a flexible tube 104. Within the flow generator is provided a blower, in the form

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of a motor 110 driving an impeller 112. The motor 110 is speed controlled by a servo 114, and in this way the pressure of gas supplied to the mask can be controlled. A controller 116 provides a controlling signal to the servo 114. The controller also provides output data to operator displays 118, and has an external interface port 120 for programming and diagnostic purposes. Operational signals from switches 122 also are received by the controller 116.

A flow sensor 130, in accordance with any one of the embodiments described above, is located in the outlet conduit 132 extending from the impeller housing. The output flow signal 134 is provided to the controller 116 where, in accordance with a relevant known voltage versus flow characteristic (whether determined experimentally or theoretically, such as in Figs. 10 and 11), is applied to determine the absolute value of flow. This flow information can then be processed in any known manner to control the supply of CPAP or assisted ventilation treatment pressure to a patient.

Advantages given by a measuring device in accordance with one or more embodiments of the invention over prior art flow meters include that:

- (1) It has a good dynamic response due to the low inertia of the vane and fast electrical response of the light detector.
- (2) There is a low pressure drop across the vane due to the narrow width and small area.
- (3) It is simple to construct.
- (4) It has a theoretical infinite resolution when using an analog electrical signal.
- (5) It has one-point calibration at zero flow point, for zero flow DC signal.
- (6) It has automatic calibration during start-up to correct for air density, relative humidity and temperature.

Although the invention has been described with reference to the specific examples, it will be appreciated by those skilled in the art, that the invention can be embodied in many other forms.